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Article

Trend of Ecological Footprint in Mongolia and Policy Directions for the Sustainable Development

Enkhjargal Volodya [1], Min Ju Yeo [1] and Yong Pyo Kim [2,*]

[1] Department of Environmental Science and Engineering, Ewha Womans University, 52, Ewhayeodae-gil, Seodaemungu, Seoul, Republic of Korea
[2] Department of Chemical Engineering & Materials Science, Ewha Womans University, 52, Ewhayeodae-gil, Seodaemungu, Seoul, Republic of Korea

* Correspondence: yong@ewha.ac.kr; Tel.: +82-2-3277-2832

Abstract: Urbanization and industrialization processes in Mongolia have been significant and rapid for the last half-century. During this period, changes in political and economic systems, growth in the population, and the occasional harsh climate conditions were subject to fluctuations in the natural resource usage. The total Ecological Footprint (EF) in Mongolia has increased from 6.8 million global hectares (gha) in 1961 to 14.6 million gha in 2012. However, Biocapacity (BC) has decreased from 50.6 million gha in 1961 to 39.0 million gha in 2012. The study shows that grazing land Footprint and carbon uptake land Footprint are the two major contributors of the recent intensified use of biological resources. To ensure stable economic development and sustainable use of natural resources, environmental planning is required to consider both the population's pressure on the environment and the ecosystem's regeneration capacity, simultaneously. We have proposed a few possible strategies for sustainable utilization of grazing land Footprint and carbon Footprint. For grazing land Footprint, efficient management of both herding practice and number of animals should be considered. In case of carbon Footprint, it is estimated that with the improved combustion efficiencies of coal-based power plants and the maximum use of renewable energy, carbon dioxide (CO_2) emissions in Mongolia can be reduced up to 30% compared to the base line business as usual case in 2030.

Keywords: Ecological Footprint; Biocapacity; resource consumption; grazing land; carbon emission; renewable energy

1. Introduction

Mongolia is a landlocked country with an area of 1.6 million km^2 surrounded by Russia and China. Its topography is comprised of the Gobi Desert to the south and hilly mountainous areas to the north. In Figure 1, a land cover map is shown [1]. Mongolia's population reached 3.1 million in 2016 [2], one of the least densely populated countries, yet its two-thirds live in the capital, Ulaanbaatar. After the change from a socialist economy to a market economy in the early 1990s, there has been a remarkable increase in economic growth and population, and accompanying urbanization and lifestyle changes. Cashmere production has significantly increased that Mongolia has become the second largest producer of cashmere after China [3]. In addition, its mining sector witnessed rapid growth due to the country's vast mineral resources such as copper, gold, and coal [4]. Accordingly, the gross domestic product (GDP) per capita has grown six-fold in the last two decades [5].

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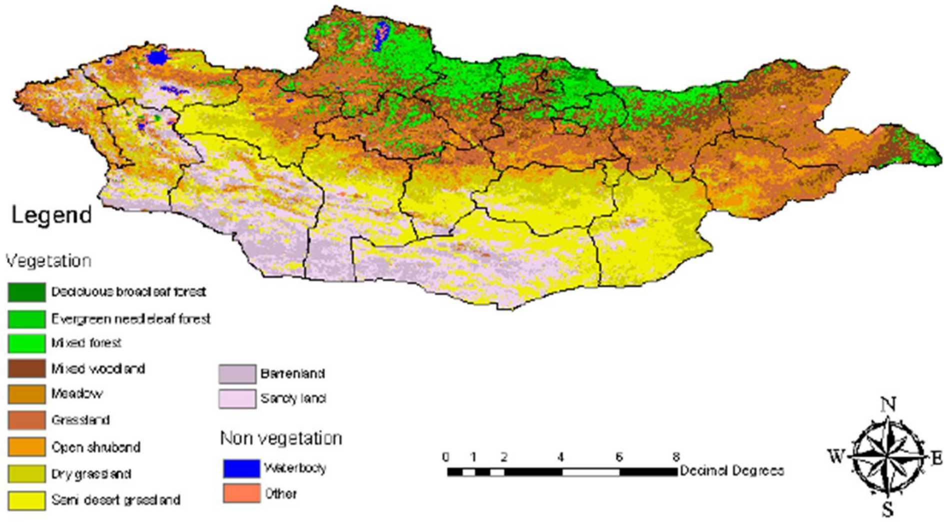

Figure 1. Land cover map of Mongolia in 2009. Source: Dulamsuren et al. [1].

The natural resource reliant economy supports Mongolian rapid development, yet combined with natural factors, such as climate change, it is posing danger to the environmental balance. Studies have shown that ecosystems in Mongolia are particularly vulnerable to climatological changes due to its high altitude and inconsistent low level of precipitation [6,7,8]. Increased anthropogenic disturbances—mining, overgrazing pasture lands, inappropriate usage of crop lands, and deforestation—cause extreme soil destruction, intensified land degradation, and frequent sand storm. The fifth national report on biodiversity [9] states that around 90% of Mongolia's pasture land is disturbed by land degradation. In addition, cold winters that follow a period of drought can lead to a “zud”, a natural disaster when thick snow prevents animals from consuming fodder, causing livestock to die of starvation [10]. Due to three consecutive zuds occurring between 1999-2002, about 11 million livestock, one-fourth of the total population were lost [11]. Subsequently, residents moved into the capital, many of them had settled down in the “ger districts” where usage of wood or coal-burning stoves for heating and cooking is common, leading to a major increase of air pollution in the capital [12,13].

Mongolia’s energy supply relies on domestic coal production and imported petroleum. While coal burning for heating and cooking in most developed countries has diminished significantly due to its impact on air pollution and climate change, combined heat and power (CHP) plants in Mongolia are all coal-based and fed predominantly on lignite [14]. There has been an increasing shortage of load in the power system recently, unabated industrial demand is compensated by additional purchases from Russia. In assessment of these challenges, the Government of Mongolia (GoM) is well aware of the problems and seeking to advance energy efficiency and security. Alternative fuel solutions include introducing super critical pressure coal combustion technology and gas-based power plants in the power system [15]. To maintain and improve long-term well-being, Mongolia should use natural resources more efficiently and reduce its consumption impacts on the environment. Therefore, growth in a developing country, such as Mongolia, needs to be measured against the ability to progress sustainably.

Several approaches have been developed to simultaneously assess for sustainability on the environmental side and anthropogenic impact on the earth (e.g., [16,17,18,19]). Among these, one of the most commonly used and widely acknowledged method is the assessment of Ecological Footprint (EF) [20]. The EF systematically evaluate environmental pressures and the biologically useful area needed to support people’s activities or progress [21,22,23]. According to Borucke et al., [24], EF measures impacts on the area that is identified as exploited, and can assist for developing targets as well as tracking progress for reaching ecological balance.

In this study, to suggest environmentally sound management directions for Mongolia, the concept of EF is used (1) to analyze the trend of environmental status, (2) to analyze the current major

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environmental problems, and (3) to present possible policy directions for sustainable development, especially, on the grazing land (livestock) and carbon uptake land (energy) in Mongolia.

2. Methodology and Data

2.1. Calculation of Ecological Footprint and Biocapacity

Global Footprint Network (GFN) calculated EF of more than 200 countries in its 2016 edition of National Footprint Accounts (NFA) [25] which covers year from 1961 to 2012 incorporating data from International Energy Agency (IEA), Food and Agriculture Organization (FAO), United Nations Statistic Division (UNSD), and around 20 other sources [26]. Along with EF, the calculation result of Biological Capacity (BC), or in short Biocapacity is presented in the NFA. As defined in The Guidebook 2016 to NFA, BC is the ecosystem capacity to regenerate and produce biological recourses that are used for the population. In this study, we used Mongolian EF and BC data obtained from the 2016 edition of NFA to analyze the country's natural resource usage trend during the past half-century.

There are six types of land use that EF examines—cropland, grazing land, fishing ground, forest land, carbon uptake land, and build-up land. For consistent global scale calculation, they are measured in global hectares (gha) which is the accounting unit for the world average biologically productive area given a specific year [26].

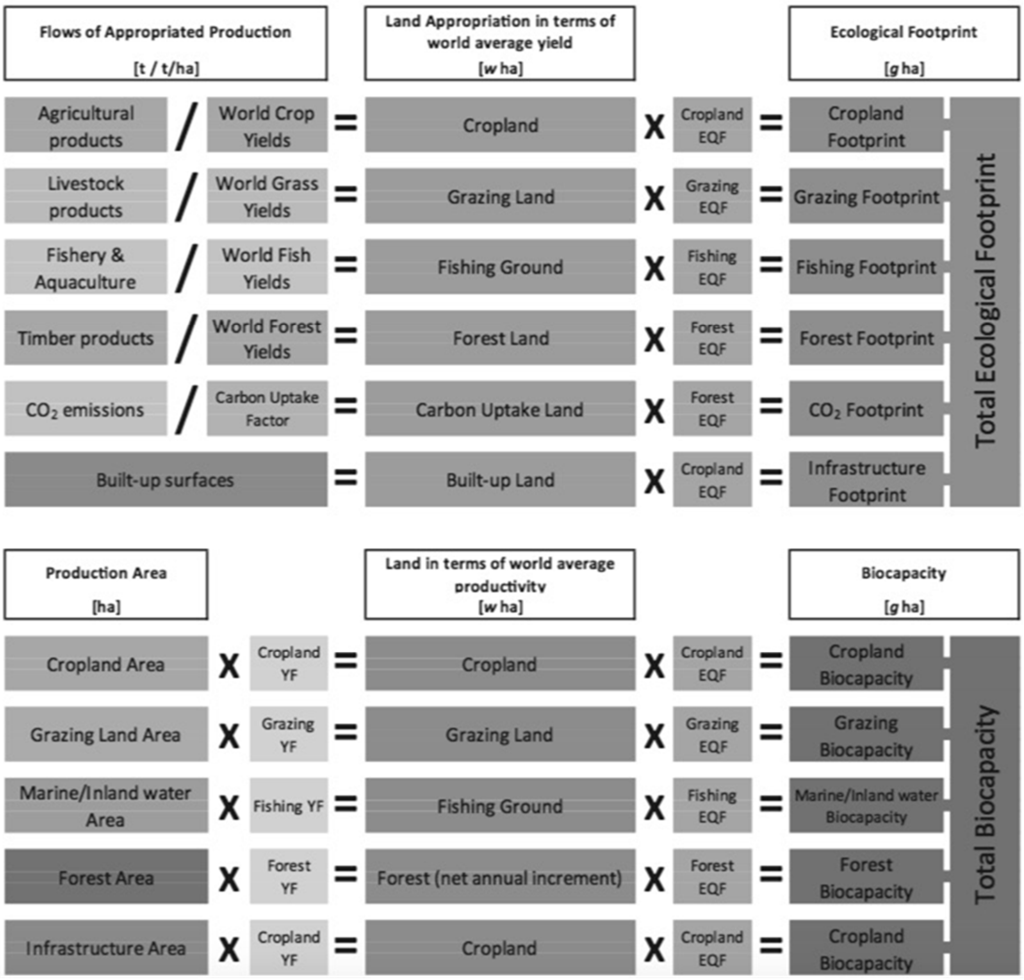

Figure 2. Accounting framework of National Footprint Accounts. Source: Borucke et al. [24].

In Figure 2, the framework of accounting both EF and BC are presented. Among them, the primary production of food—meat, fiber, oil; and wood—timber, fuelwood, paper concern the four

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area of cropland, grazing land, fishing ground, and forest land. Their EF and BC are calculated by equations (1) and (2), respectively:

$$EF_i = \left(\frac{Consumption\ (pro+im-ex)}{Yield}\right) * f_y * f_{eq}, \quad (1)$$

where EF_i is for the EF of specific *i* area type (gha), ***Consumption*** is equal to annual production plus import minus export, in other words, the quantity of annual consumed product from area type *i* (t yr^{-1}). ***Yield*** is the national annual average yield for the ***Consumption*** (t nha^{-1} yr^{-1}), f_y is the yield factor for converting the national average yield to the world average yield (wha nha^{-1}), and f_{eq} is the equivalence factor for the specific *i* area which varies depending on the year and land usage (gha wha^{-1}).

$$BC_i = Area * f_y * f_{eq}, \quad (2)$$

where BC_i is for the BC of specific *i* area type (gha), ***Area*** is the specific *i* area type within in a country (nha). f_y is the yield factor for converting the national average yield to the world average yield (wha nha^{-1}) and f_{eq} is the equivalence factor for the specific *i* area which varies depending on the year and land usage (gha wha^{-1}).

In the EF methodology, as Galli et al. [27] and Marcini et al. [28] clarified, carbon uptake land refers to the forest area required to absorb anthropogenic carbon dioxide (CO_2) emissions. Hence, in the carbon Footprint calculation forest area equivalent factor is used to convert the amount of emissions to the consistent measurement of gha, presented in the equation (3):

$$carbon\ Footprint = \left(\frac{CO2\ emission}{Carbon\ Uptake\ factor}\right) * f_{forest\text{-}eq}, \quad (3)$$

where ***carbon Footprint*** is the annual average amount of biologically productive forest area needed to absorb CO_2 emissions (gha), ***CO_2 emission*** is the amount of anthropogenic carbon dioxide emissions allocated to a specific country based on the country's fossil fuel usage and the share of international imports (Mt CO_2), ***Carbon Uptake factor*** or the yield factor for carbon is the world annual average yield of forest land (wha nha^{-1}), and $f_{forest\text{-}eq}$ is the equivalent factor of the forest land that needed to absorb CO_2 emissions (gha wha^{-1}).

Lastly, the infrastructure Footprint which NFA considers as the area where formerly cropland is now occupied for human settlement such as housing, industrial construction, and transportation. Therefore, the built-up land regeneration area or BC refers to the cropland yield factor and the equivalent factor. The equations (4) and (5) describe Build-up land EF and BC, respectively:

$$Build\text{-}up\ land\ Footprint = Build\text{-}up\ surface\ areas * f_{cropland\text{-}eq}, \quad (4)$$

where ***Build-up land Footprint*** is the area occupied with human infrastructure (gha), ***Build-up surface areas*** is the area previously used as cropland (wha), and $f_{cropland\text{-}eq}$ is the equivalent factor of the cropland that accounted as build-up land (gha wha^{-1}).

$$Build\text{-}up\ land\ BC = Infrastructure\ area * f_{cropland\text{-}y} * f_{cropland\text{-}eq}, \quad (5)$$

where ***Build-up land BC*** refers to the same amount of area as cropland BC (gha), ***Infrastructure area*** is the same amount of biological area as cropland (nha), $f_{cropland\text{-}y}$ is the annual cropland yield factor for converting the national average yield to the world average yield (wha nha^{-1}), and $f_{cropland\text{-}eq}$ is the equivalent factor of the cropland that accounted as build-up land (gha wha^{-1}).

In short, after converting national average yield value to the land appropriation in terms of world average yield, each land type is translated into gha value by the equivalence factors which varies depending on the land type and year for every country. In 2012, for example, cropland in Mongolia had an equivalence factor of 2.55 gha wha^{-1} (Table 1), indicating that cropland was more than twice as prolific as the world average crop land. In that same period, grazing land, however, had 0.43 gha wha^{-1} of the equivalence factor showing that grazing land was half productive as the world average.

Table 1. Equivalence factors for 2012 in Mongolia.
Data source: Global Footprint Network in 2016. [25]

Land use type	Equivalence Factor (gha wha^{-1})
Cropland	2.55
Grazing Land	0.43
Fishing Ground	0.35
Forest Land	1.27

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Carbon Uptake Land	1.27
Built-up Land	2.55

In order to determine whether a certain country is beyond or below its BC limit, EF is subtracted from BC [29]. In case, the EF is larger than its BC, it's called the Ecological deficit (BC<EF). If not, it's called the Ecological remainder (BC>EF).

2.2. Data and Materials

Based on the information we constructed three steps of study as shown in Figure 3. In the first step, the six categories of EF changes in Mongolia are illustrated using the data obtained from NFA [25]. With the same data, we estimated the year when ecological overshoot is most likely reach by employing linear regression analysis method, built on the increase rate of the total EF and the decrease rate of the total BC. Among the six types, we narrowed down the research focus on the two major Footprints that make up the most of the EF and BC in Mongolia.

Second, we examined the impact from country's social and economic changes on the environment and vice versa, throughout the timeline. We referred to the open data sources, e.g. World Bank statistics [5], National Statistical Office of Mongolia [2,11,30], International Energy Agency [14] and the Ministry of Energy [31], to elaborate the correlations.

As for the third step, we explored further sustainable development options in Mongolia. Using current national policy for preventing environmental degradations [13] as a guide line, we studied and compared additional mitigation options presented by the international organizations, e.g. Asian Development Bank [32,33,34,35] and Global Green Growth Institute [36]. For carbon Footprint mitigation possibilities, we approximated CO_2 emission levels until 2030 and developed two scenarios based on the ADB's assumption on Mongolian's energy prospective [30]. In the process of estimating CO_2 emissions, we have used default emission factors presented in the Guidelines for National Greenhouse Gas Inventories (IPCC) [37]. Then applied them in the annual growth rate of coal usage calculation to obtain two different emission scenarios.

In Table 2, data and materials used in the steps are shown followed by their sources.

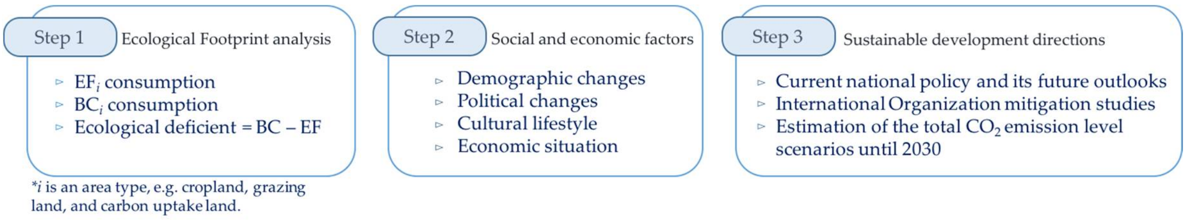

Figure 3. General flow of the study

Table 2. Data and materials used in this study.

Data		Source
1) Ecological Footprints & Biocapacity - Cropland - Grazing land - Forest land - Fishing ground - Built-up land - Carbon uptake land	⇒	Used Mongolian data 1961-2012 provided by Global National Footprint (2016)
2) Estimation of the ecological deficit point	⇒	Calculated based on (1) the total Ecological Footprint and the total Biocapacity data 1961-2012
3) Mongolian population & population per/capita (US)	⇒	Used World Bank statistics data on Mongolia in 2017

4) Livestock population	⇒	Used the data presented in the National Statics Office in 2017
5) Electricity generation from coal-fired power plants 2012-2016	⇒	Referred to the Annual statistics book published by Ministry of Energy in 2017
6) CO_2 mitigation target levels and policy measurements for 2023 and 2030	⇒	Referred to the Intended Nationally Determined Contributions submitted by Mongolia to the Ad-Hoc Working Group on the Durban Platform for Enhanced Action, UNFCCC (2014)
7) Estimation of CO_2 reduction options		
a. LEAP program based power plants CO_2 emission scenarios 2015-2035	⇒	Referred to the final report of Strategies for Development of Green Energy Systems in Mongolia, presented by the Global Green Growth Institute in 2014
b. ADB study on CO_2 emission mitigation scenarios 2015-2035	⇒	Referred to the Mongolian emission scenarios of the Energy Outlook for Asia and the Pacific, published by Asian Development Bank in 2013
c. Our scenarios based on (6) the government CO_2 mitigation targets for 2023 and 2030	⇒	Calculated assuming (b.) ADB business as usual scenario as a base line. After applying the government measurements and our own extended scenario measurements, we converted the reduced amount of the coal usage that goes to electricity generation to CO_2 emission scenarios using default emission factors presented in the Guidelines for National Greenhouse Gas Inventories in 2006

3. Results and Discussion

3.1. Variation of Ecological Footprint

Variations of the total EF, BC, and population growth of Mongolia between 1961-2012 are shown in Figure 4. Mongolia's total EF consumption in 2012 was estimated to be 14.6 million gha or 5.23 gha per capita. Over the period of 1961-2012, the population grew significantly, from about 982 thousand to 2.8 million [2]; correspondingly the total EF doubled as it was 6.8 million gha in 1961. For the total BC in 1961, it was 50.6 million gha and by the year 2012 it had declined to 39.0 million gha, and same as for per capita of BC, from 51.52 gha per capita to 13.92 gha per capita respectively. The EF accounts of Mongolia depict an increasing trend, indicating the resource consumption in the country has risen, yet the BC remains larger than the EF.

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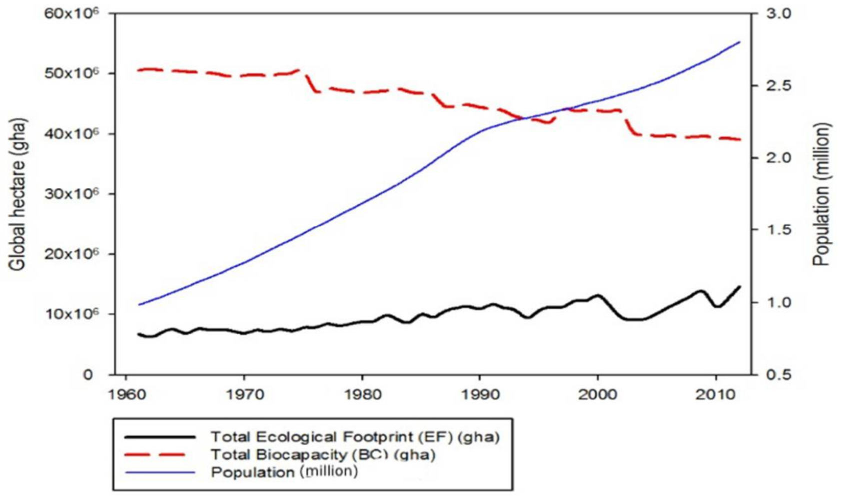

Figure 4. Trend of the total Ecological Footprint, the total Biocapacity, and the population of Mongolia between 1961-2012. Data sources: GFN 2016 [25], and NSO 2017 [2].

More in detail, Figure 5 shows the Mongolian biologically productive area Footprints of six categories. Among these categories, Footprints of grazing land and carbon uptake land have risen recently, while those of forest land, cropland, fishing grounds, and built-up land have gone down heavily since the early 1980s. In the cases of fishing grounds and built-up land footprints, the EF have been equal to or less than 1% of the total EF, respectively, throughout the timeline. Footprints of cropland and forest land reached their peak in 1981, accounting 10.3% and 17.3% of the total EF, respectively, but have declined significantly since then.

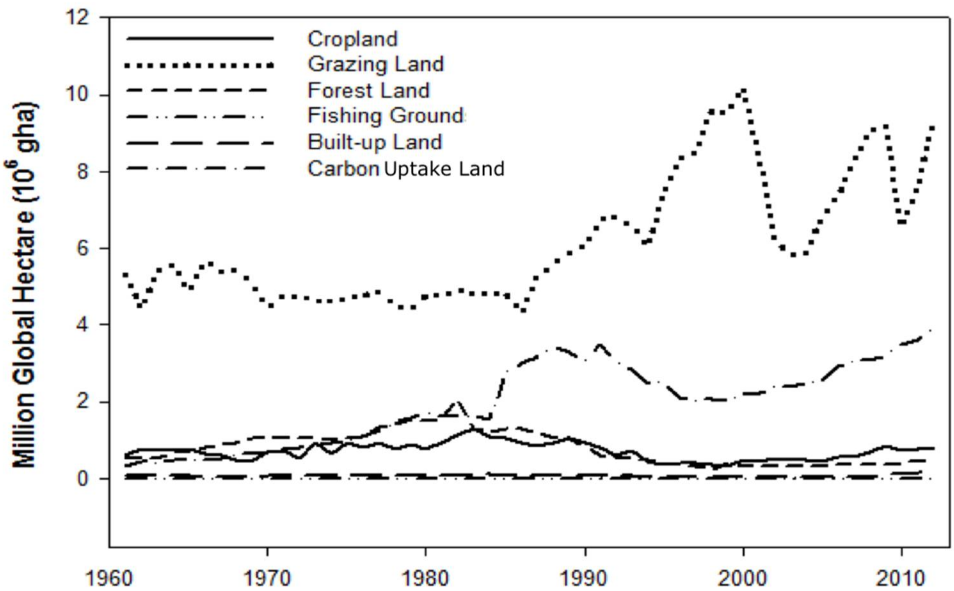

Figure 5. Six categories of Ecological Footprint in Mongolia 1961-2012. Data source: GFN 2016 [25].

Additionally, the fraction of each sector (in percent) to the total EF for every 10 years and the maximum value of each sector are shown in Table 3. In 2012, 63.5% of Mongolia's EF was from grazing land Footprint and 26.6% from carbon Footprint, while the sum of the other Footprints made only 9.9%. Thus, further analysis is carried out for the grazing land Footprint and carbon Footprint as these two categories generally make the most of EF in Mongolia.

Table 3. Trend of each land type in the total Ecological Footprint in Mongolia 1961-2012. Data source: GFN

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2016 [25].

Year	Cropland	Grazing Land	Fishing Ground	Forest Land	Carbon Uptake Land	Built-up Land
1961	8.6%	78.1%	0.10%	7.6%	4.6%	0.9%
1971	9.6%	64.6%	0.08%	14.5%	10.2%	0.9%
1981	10.3%	53.5%	0.06%	17.3%	17.9%	0.7%
1991	6.8%	57.8%	0.04%	5.0%	29.9%	0.6%
2001	4.0%	73.5%	0.02%	2.8%	19.3%	0.3%
2012	5.6%	63.5%	0.06%	3.2%	26.6%	1.0%
max	**10.3% (1981)**	**78.1% (1961)**	**0.10% (1961)**	**17.3% (1981)**	**29.9% (1991)**	**1.0% (2012)**

3.1.1. Grazing land Footprint

Grazing land of which the total EF comprised more than 63% in 2012, is a vital livelihood natural resource for Mongolian. In 1961, grazing land footprint was 5.3 million gha and by the year 2012 it had grown up to 9.3 million gha. Over the period of 51 years, the amount of grazing land footprint has been fluctuating as a result of interaction between variation in livestock numbers and climate conditions.

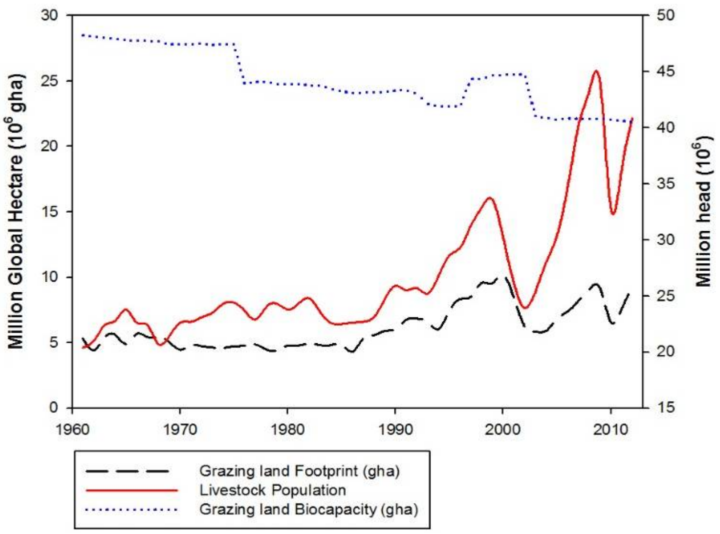

Figure 6. Grazing land Footprint, grazing land BC, and livestock population in Mongolia 1961-2012. Data source: GFN 2016 [25] and NSO 2017 [30].

Between 1961 and 1991 the livestock population was relatively stable, ranging from 20.4 million to 25.5 million [30], respectively (see Figure 6). However, in the early 1990s, after the political and economic transition, the collective patrol system was dismantled and previously state-owned livestock was privatized which resulted in rising livestock numbers and a reduction in overall mobile pastoralism [38]. Studies of Lise et al. [39] and Hilker et al. [40] show that this privatized management led to not only upsurge in livestock density but also increased grazing pressure in certain places near settlements and water sources. Particularly, the number of goats has progressively grown throughout

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the country as rural residents' income has been mostly met by cashmere products [41] which in turn resulted in grassland degradation [42,3,43].

Livestock population and grazing land Footprint both have been increasing in the past two decades and show positive correlation. During 1992 and 1999, the total livestock population rapidly increased. Same as for the grazing land Footprint that grew gradually until 2000, which indicated the first peak as shown in Figure 6. This peak was followed by a rapid and steady decline from 2000 to 2003 due to consecutive years of drought and zud [44] and it reached its lowest point. Another increase for the second peak was in 2009. However, in 2010, livestock number declined due to historically exceptional harsh winter of 2009-2010 [45] and so did the grazing land Footprint, dropped from 9.2 million gha to 6.5 million gha.

From 1961 to 2012, grazing land BC has declined from 28.5 million gha to 21.8 million gha, as shown in Figure 6. Fensham [46] and Bertiller [47] have shown that heavy grazing leads to decline in plant diversity, vegetation cover, and disturbance in the seed production of soil. During the latter part of the 20th century Mongolia's grazing land BC has been declining due to population growth, land-use changes, and climate conditions which eventually promoted soil degradation. More recent studies based on satellite measurements such as vegetation optical depth (VOD) which measures biomass water content in vegetation, and the normalized difference vegetation index (NDVI) which graphically indicates the chlorophyll richness in green plants cover; demonstrated that from 1993 to 2012 grassland cover in Mongolia have degraded due to rapid growth in livestock population [48].

3.1.2. Carbon uptake land Footprint

The carbon uptake land Footprint or carbon Footprint is estimated by amounting the biologically productive area such as forest land required to assimilate the emission from burning fossil fuels. In other words, it is the amount of forest area (gha) needed to absorb carbon dioxide (CO_2) [49]. In Mongolia, carbon Footprint increased from 0.32 million gha in 1961 to 3.5 million gha in 1991. The biologically productive area needed to assimilate carbon dioxides has enlarged more than 11 times in 30 years. Over the period of 1992-1999, carbon Footprint showed a downward trend, as the economy declined during the transition period [50,51]. After 2000, however, CO_2 emissions from fuel combustion have continuously increased that the carbon Footprint reached 3.9 million gha in 2012, of which about 60% accounted for heat and power production, 14% for industrial processes, 13% for transportation, and 13% for others. Based on available data from NFA, the period between 1985 to 2012 shows that heat and power generation dominated and made up the most of the carbon Footprint in Mongolia as shown in Figure 7.

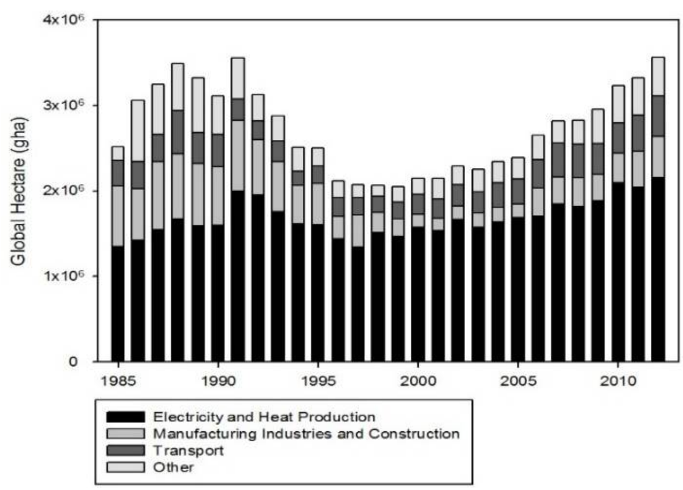

Figure 7. Formation of carbon Footprint in Mongolia 1985-2012. Data source: GFN 2016 [25].

The power demand throughout the country is expected to rise. Growing levels of urbanization combined with mining activity expansions have become the leading forces of the country's

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intensified energy demand. In the business as usual (BAU) scenario, Mongolia's demand on the primary energy is estimated to grow from 3.3 Mtoe in 2010 to 12.1 Mtoe in 2035 as shown in Figure 8. By energy usage type, coal share will remain dominant reaching 74.9% in 2035, and the leading force will be the power generation [34].

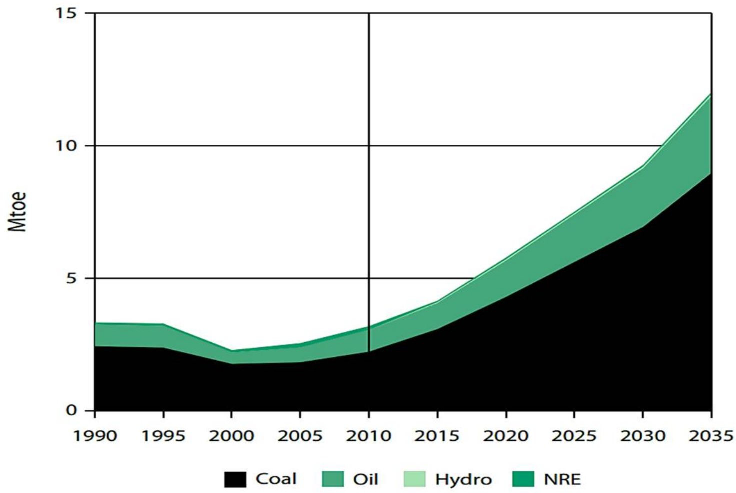

Figure 8. Estimated primary energy demand in Mongolia 1990-2035. Data source: ADB 2013 [34].

In addition, the amount of carbon Footprint in Mongolia rises due to increased economic activity. The mining sector output makes up around 33% of the country's gross domestic product (GDP) and around 70.3% of the total value of industrial productivity [52]. In Figure 9, the estimated trend of GDP per capita (US$) and carbon Footprint (gha) in Mongolia over the period of 1981-2012 are shown. Both trends display positive correlation throughout the period and show constant increase in the last decade.

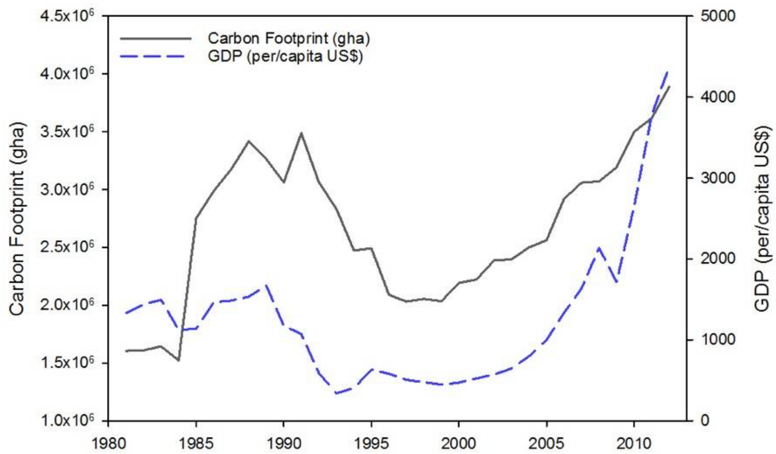

Figure 9. GDP (per/capita US$) and carbon Footprint (gha) in Mongolia 1981-2012. Data source: World Bank 2017 [5] and GFN 2016 [25].

3.1.3. Estimated Time Span for the Ecological Deficit

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To estimate a point where Mongolia's total BC becomes no longer sufficient to support the competing demands or the EF, a linear regression analysis method is applied using the past 51 years of total EF and BC data. As presented in Figure 10, if the development of Mongolia continuous in the same way, i.e., linear trend, the county's ecological deficit (or overshoot) point is likely to reach by the year 2083.

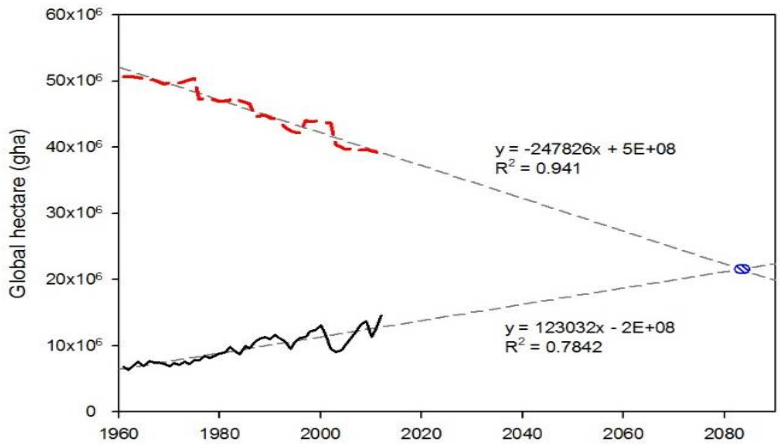

Figure 10. Ecological deficit trend in Mongolia, starting from 1960 and reaching overshoot in 2083.

In other words, with the current rate of population and economic growth's demand on nature, overshoot is possible to occur in about 70 years in Mongolia. On the global scale, EF surpassed BC in the early 1970s. As of 2012, it was estimated that 1.6 earth BC equivalent required to replenish the natural resources [53]. According to the assessment, this is due to the high-income countries having maintained EF per capita greater than the BC available per capita.

3.1.4. Limitations in the Ecological Footprint Analysis

There are a few limitations in the EF method due to its theoretical structure, while its core ability to address the sustainability assessment is undeniable. As [54] noted, when converting regional scales into global average productivity quantity, there could be possible numerical errors. In terms of calculation, double counting may occur due to mutual land usage of the equivalence factor. For example, the forest land equivalence factor is used in both forest land Footprint and carbon Footprint, and the crop land equivalence factor is repeatedly used in cropland Footprint and build-up land Footprint.

Also, Venetoulis and Talberth [55] further identified that the equivalence factors may vary each year within the range of available information. Global Footprint Network utilizes annual data obtained from IEA and FAO, yet in the same period domestic statistics may differ slightly. For more comprehensive EF analysis, an indicator of freshwater consumption, water Footprint, should be included. Also, economic and social factors are considered highly correlated to the amount of EF and BC of a nation, yet the characteristics of income and environmental variation among countries are not included in the explaining variables [56].

3.2. Future Policy Directions

After a rapid economy growth, concern over environmental degradation is rising in Mongolia and demands for adaptation strategies and policy planning relevant to ecological impact are increasing. To respond to these challenges, the Ministry of Environment and Green Development (MEGD) was established in August 2012, with the status of a core ministry. Also, in June 2014, to address fundamental goals of sustainability, Mongolian parliament approved the Green Development Policy (GDP) [57]. The national strategic plan for effective grazing land usage focus mainly on livestock number regulation, improved carrying capacity, and development of local

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farming. For efficient energy usage strategy, GDP addresses the development of low carbon consumption and promotion of clean technology [15]. Since two types of land, grazing land and carbon uptake land are major EFs, we suggest policy directions for these two.

3.2.1. Grazing land Footprint

In Mongolia, sustainable livestock use of BC to satisfy social, economic and dietary needs is one of the vital assets. Grazing management strategy using values derived only from economic factors that are irrelevant to ecological principles has been used but it is impractical in the point of sustainable development [58]. Management decisions should take limitation of grazing land Footprint and sustainable usage of BC into consideration. Accordingly, for grazing land management, two objectives can be considered; (a) encouraging the long-distance movement of livestock and (b) regulating the livestock population with improved efficiency output.

a. Encouraging the long-distance movement of livestock

Mongolian grazing land Footprint increased and the BC decreased significantly due to overgrazing. The local system and policies prevents long distance movements and seasonal traveling of livestock [31]. In fact, some *sums* (a district of a province) have disintegrated foraging lands that are impractical to use as four seasonal pastures, which in turn intensifying overgrazing in certain areas [59]. The effect of continuous grazing results in a substantial decrease in soil biological properties such as soil organic carbon (SOC) and soil nitrogen (N) [60,61] that control vegetation ability to recover and regenerate.

To reduce the rate of grazing land degradation and to increase the frequency of pasture land rest, therefore, it is important to improve herders' access to participate in *otor*, which is Mongolian herders' traditional way of long-distance migration. As Xie and Li [62] illustrated that this practice has positive consequences on rangelands sustainability and livelihoods of pasture.

b. Regulating the livestock population with improved efficiency output

After the privatization of livestock management in the early 1990s, the total number of livestock surged from 25.1 million in 1993 to 66.2 million in 2016 [30]. Horse, cattle, sheep, goat, and camel are the major five animals used for livestock in Mongolia. Their population fluctuations for each animal type from 1970 to 2016 are illustrated in Figure 11. The proportions of sheep and goat show drastic growth while horse, cattle and camel maintained a relatively stable trend in the total livestock number.

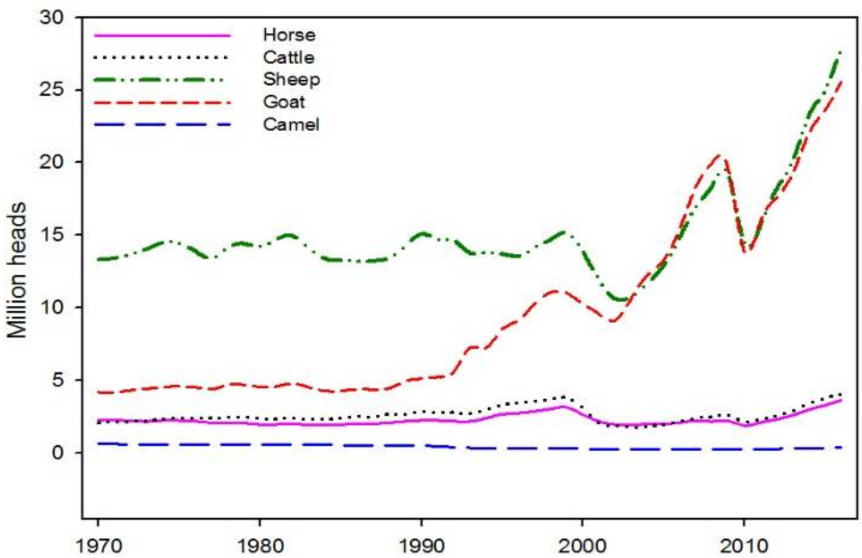

Figure 11. Mongolia's livestock population 1970-2016. Data source: NSO 2017 [30].

The numbers of sheep and goat continuously increased due to encouragements of cashmere sales, except the periods when *zud* (or extremely cold winter) occurred. In terms of pasture grazing

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patterns, active forager sheep and goat graze more intensively from top to the bottom while horse, cattle, and camel consume the upper part of plants [57]. Additionally, for production wise, incentive system for the quality improvement of livestock output has not introduced in the current marketplace [35]. So, the increased quantity of livestock does not ensure efficiency. Thus, for prevention of further grazing land BC loss, livestock management should take livestock reproduction rates into accounts while increasing livestock off-take product efficiency.

3.2.2. Carbon Footprint

More than 90% share of the total primary energy supply in Mongolia comes from coal and oil, of which majority feed to coal-based combined heat and power (CHP) plants [14]. Because of aging facilities and high internal electricity usage, efficiency of the CHPs is low as between 20% to 44%. For instance, out of three coal-based CHP plants located in Ulaanbaatar, two CHPs have operated for more than 50 years without proper emission control devices, and the one which has the highest capacity, CHP 4 has operated for more than 35 years [31] (see Table 4). Although other sources of energy such as hydro, wind, and solar installments have been introduced, their overall installed capacity takes around 4.2% of the total electricity generation, as of year 2016, shown in Table 5. Also, as shown in Table 5, electricity output is increasing and power demand is estimated to grow continuously [31]. To supply the Mongolia's ever-increasing energy demand, efficient and sustainable energy development strategies ought to focus on rehabilitation in the current existing CHPs and intensive investment in renewable energy sources. Accordingly, mitigation possibilities for the reduced carbon Footprint can be grouped into (a) efficiency improvements in the existing system and (b) shifting to less carbon-intensive energy sources.

Table 4. Coal-fired power plants in Mongolia. Data source: Ministry of Energy 2017 [31].

Combined Heat & Power Plant	Capacity (MW)	Internal Electricity Use	Overall Efficiency	Year of Commission
Ulaanbaatar CHP2	24	14%	20.9%	1961
Ulaanbaatar CHP3	186	17%	44.0%	1968
Ulaanbaatar CHP4	703	12%	42.4%	1983
Darkhan	48	17%	27.5%	1966
Erdenet	28.8	20%	41.3%	1987
Choibalsan	36	14%	19.5%	1969
Dalanzadgad	6	-	-	2000
Total	**1031.8**			

Table 5. Electricity generation in Mongolia 2012 - 2016. Data source: Ministry of Energy 2017 [31].

Source	2012	2013	2014	2015	2016
Heat power plant	4,775.5	5,014.0	5,191.3	5,415.8	5,555.9
Diesel power plant	28.7	5.4	8.2	6	3.8
Solar energy	-	-	0.6	0.5	0.3
Hydro power plant	52.1	59.9	66.3	59.3	84.7
Wind power plant	-	52.9	125.4	152.5	157.5
Total	**4,856.3**	**5,132.2**	**5,391.9**	**5,634.2**	**5,802.4**

Unit: million kWh

a. Efficiency improvements in the existing system

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The total current capacity of the installed CHP plants is 1031.8 MW, not sufficient to meet even the present demand in Mongolia. The electricity generation covers around 80% of the demand and remaining is purchased from Russia [31]. Due to various reasons, such as low efficiencies of the boilers and steam generation, excessive internal heat and power consumption, and low condensate yield, the fuel utilization is inefficient, 20-44% [63]. In comparison, a modern coal-fired CHP plant can achieve 50-80% fuel utilization efficiencies depending on the technologies and heat load profiles [64]. At present, supercritical and ultra-supercritical power plants are the option for a new CHP.

To introduce these technologies efficiently, for example, building a new CHP plant at the existing site of an old and inefficient CHP is practical. The equipment in the CHP plant 2 and plant 3, specifically, have been operating for over fifty years. The expected lifespan of the CHP plant 2 ended in 2005, and of the CHP plant 3 in 2011 [33]. Therefore, using existing land and infrastructure such as roads and water supply sources is economically advantageous for building a new coal-fired CHP plant.

Another possible way is constructing a new CHP plant near the coal mine area of Baganuur, located approximately 120 km east of Ulaanbaatar. This option is, theoretically, intended to relocate the power plant from urban area to a coal mine mouth. Hence, mitigating air pollution in urban areas and at the same time avoiding long distance transportation of coal for heat and power generation.

b. Shifting to less carbon-intensive energy sources.

Encouraging the installment of low carbon emission energy sources can significantly reduce carbon Footprint. Renewable energy is a clean and economical competitor that can replace the existing power generation system [65] as the country is in rich solar and wind energy resources due to geographical distinctiveness. The IEA has evaluated that Mongolia has potential to generate around 2.6 million MW using renewables [66]. This potential power generation present opportunity to accelerate overall economic activity, also it can play a chief role in meeting CO_2 emission reduction targets set by the Government.

Another less carbon-intensive energy source that is simultaneously applicable in Mongolia is to construct a facility that combusts wastes to produce electricity. There is no waste incineration for generating power, and according to Japan International Cooperation Agency (JICA) [67], more than 90% of Ulaanbaatar's waste goes to the Ulaan Chuluut disposal site. Based on the assumption that the rate of waste generation will intensify in proportion to the population growth rate and increase in GDP, the study evaluated the total aggregated municipal solid waste (MSW) in the year 2020. The estimation show that 79.8% of MSW generated in the summer and 56.4% of MSW generated in the winter is combustibles, and the rest consists of non-combustibles and ash. Thus, there is a room for obtaining energy by waste incineration.

3.2.3. Estimation of CO_2 Reduction Options

To broaden the perspective, we referred to the Global Green Growth Institute (GGGI) study on CO_2 emission level prediction in Mongolia [36] and compared the result with our own estimation. To estimate the degree of reducing carbon Footprint, we have collected existing CO_2 emission scenario results and carried out a simple calculation on the CO_2 emission amount based on the Asian Development Bank (ADB) study [34] and Mongolian Government goal [15].

First, the GGGI used the Long-range Energy Alternatives Planning (LEAP), a software tool developed by Stockholm Environment Institute, to analyze low emission strategy developments in Mongolia between 2010 to 2035 [36]. Assuming there will be a rapid increase in the industrial sector and based on the same economic and population growth rate calculation, the GGGI presented three scenarios, reference or business as usual (BAU) scenario, a scenario implementing recent plans by the Government on the energy usage, and the one with extended green energy policies beyond the Government's plans. For comparison purpose, three scenarios outcome from year 2015 to 2030 on the CO_2 emission amount is shown in Figure 12a, where estimated amount of 20Mt CO_2 emission in 2015 is projected to rise to 49Mt CO_2 for BAU, 43Mt CO_2 for the recent plans scenario, and 27Mt CO_2 for the extended green energy scenario in year 2030.

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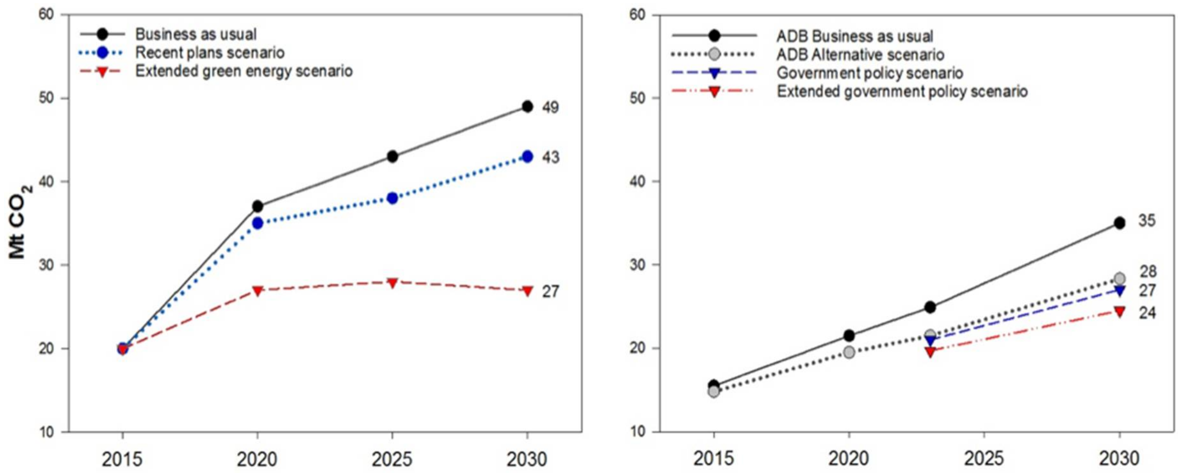
Another emission scenario study that can be proposed is in the Energy Outlook for Asia and the Pacific report published by ADB [34]. ADB's BAU case presents an outlook on coal usage using existing level of technology applications, while the alternative case assumes the use of advanced thermal technologies. Two cases outcome from year 2015 to 2030 on the CO_2 emission amount is shown in Figure 12b.



a. GGGI scenarios **b.** ADB and our study scenarios

Figure 12. Comparison of estimated CO_2 emission from the power plants. **a**. GGGI study on three different emission scenario results from 2015 to 2030 are shown [36]. **b.** ADB analysis on two emission scenarios from 2015 to 2030 [34] and our proposed two emission scenarios based on the government policy from 2023 to 2030 are shown.

The Government of Mongolia has announced a two-phase renewable energy target to expand the efficiency of energy use. The aim is increasing renewables as a portion of total electricity generation capacity up to 20% and decrease building heating loss 20% by 2023, and to further increase the renewables to 30% and the heating loss 40% by 2030 [15].

If the Government's renewable energy target is included to the ADB's alternative scenario, i.e., a part of electricity supply from CHPs is replaced by renewables, the total coal usage can be effectively decreased, resulting in a proportionate decrease in primary energy demand. We developed two scenarios, Government Policy Scenario (GPS) and Extended Government Policy Scenario (EGPS).

In the GPS, we follow the government's goal of replacing 20% of the electricity production in 2023 and 30% of the electricity production in 2030 by using renewable energy. As a result, CO_2 emissions are estimated to drop by 16% in 2023 and 27% in 2030 compare to the baseline ADB BAU case. The EGPS is built on the previous scenario and assumes that the same amount of heat generation is also replaced by the power of renewable energies. Outcome can be seen that, compare to ADB BAU case, CO_2 emissions are reduced 21% in 2023 and 30% in 2030 by cutting 5.2 Mt CO_2 and 10.5 Mt CO_2, respectively. In Figure 12b, these results are summarized and we found this ambitious proposal is useful in creating a broader consensus as the technology advancement is exponentially growing.

4. Conclusions

Mongolia is experiencing a drastic development and urbanization, and facing challenges to address its sustainability. The Ecological Footprint (EF) analysis is a widely acknowledged measurement tool to assess a country's improvement towards sustainable development. Within its ability, EF analysis presents a general view on how the ecosystem or the environmental resources is utilized by the populace of the certain region. As climate change is altering the ecological balance and causing problems all over the world, it is a necessity to develop suitable mitigation strategies.

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The study shows the overall EF of the productive lands increased from 6.8 milliong gha to14.6 million gha between 1961 to 2012 in Mongolia. Its two main contributors grazing land Footprint, and carbon Footprint made up 63.5% and 26.6% of the total EF, respectfully, in 2012. Yet, the sum of cropland, forest land, fishing ground, and build-up land Footprints accounts the rest 9.9% of the total EF in the same year. The growth in grazing land Footprint, in the last two decades, indicates that ecological based manufacturing and consumption impact has intensified. Also, the rising trend of carbon Footprint implies that the overall energy consumption has increased and the further demand is expected to intensify. Correspondingly, the total BC has been declining and will gradually aggravate and reach the ecological deficit, in case not reduce vulnerability of socio-economic factors.

To improve the situation, for sustainable grazing land practice, management decisions should consider reducing the rate of grazing land degradation by advancing current regulatory system. Findings suggest that having control on headcounts of animals and regulating highly concentrated areas could be potential strategies. For reducing the amount of area needed to absorb the CO_2 emission (or carbon uptake land Footprint) generated from fossil fuel combustion, especially, the coal-based CHPs, options are advancing the current technological utilization and increasing new power supplies such as wind and solar energy. As the Government of Mongolia has declared a two-phase renewable energy goal, CO_2 emissions predicted drop by 16% in 2023 and 27% in 2030 compare to BAU scenario. For the maximum cutback, according to government target extension scenario, carbon emissions can fall by 21% in 2023 and 30% in 2030, in contrast to baseline BAU scenario.

Though there are certain limitations in using the concept of EF, Mongolia is an excellent example to test the effectiveness of the EF to analyzing and developing policy directions for the sustainable development.

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